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# OPTICAL ELECTRONICS AND INFRARED RADIATION

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The work has progressed in several fronts.
Following extensive previous work at the laboratory, properties of metal-barrier-metal submicron junctions have been explored, with respect to their high-speed responses, frequency mixing characterists, and the physical mechanisms accuring in the junction The studies are done at cryogenic tempertures and relate to the properties of the mechanically contacted junctions, as well as

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20. ABSTRACT CONTINUED

thin film evaporated junctions. Emphasis is placed on high-speed features originating from rapid variation of the I-V characterists over narrow ranges of bias voltages, causing sharp enhancements of the junctions IR responses at fixed bias fields. The model employed in the interpretation of the results is based on Fermi-level modulation by the applied high frequency field, determining the high speed current conduction properties of the junctions. In the model, electron tunnelling across low-height barriers give rise to the conduction process. In another set of activities, underway over a number of years, a highly precise broad-band two-beam interfoermeter capable of highly accurate laser wavelength measurement is developed. The work in this period has emphasized the conclusion of this project. An extensive article describing the details is published. This work covers the application of the interfoermeter to precise speed of light meausrement (via simultanous obsolute frequency and wavelenghts determenation) reported in the publication. The interforometer is capable of rapid wavelength measurements to within several part in $10^9$ in the IR and several parts in $10^{11}$ in the visible range. In another experiment, a multiatmospheric $CO_2$ laser (seed gas photopreionized), capable of reliably operating up to 15 atmospheres is developed. The work has included sealed-off operation of a high pressure isotopic $CO_2$ laser. The objective has been to obtain laser frequency tuning in the regions off $CO_2$ line centers, with a broad frequency tuning coverage without a gap. The laser has been applied as an IR pumping source, to obtain new oscillating laser lines in $CH_3$-OH in the far-IR range. The trust of the latter work has been spectroscopy and determination of vibrationally excited $CH_3$-OH molecular parameters. Other experiments successfully performed in this period under partial ARO sponsorship have consisted of development of a two-beam IR laser spectrometer and its application to hyperfine studies in $N_2O$ molecules and measurement of diamagnetism in vibrationally excited $CO_2$ molecules. Two other experiments successfully concluded have been a detailed study of the decay of the weakly bound ground electronic state of the XeF molecules, and the observation and study of (for the first time) of the motional narrowing effect in the fundamental and a high order overtone ro-vibrational transitions of the HD molecules. An extensive study of rotational relaxation in $D_2O$ molecules has also been performed, emphasizing the observation (for the first time) of exceptionally long-lived isolated rotational states.

## OUTLINE OF THE WORK PERFORMED DURING THE PERIOD 02/10/79 THROUGH 02/09/82

The work performed has progressed on several fronts. They are outlined in this report in several section, 1 through 7.

The topics reported are as follows;

1. High-Speed Sumbicron Junctions'; P!toca; Electronics

2. Accurate Laser Wavelenghts Measurements With A Precision Two-Beam Interferometer

3. Laser Spectroscopy With A Tunable High Pressure $CO_2$ Laser

4. Mixed Lsotope Multiatmospheric laser

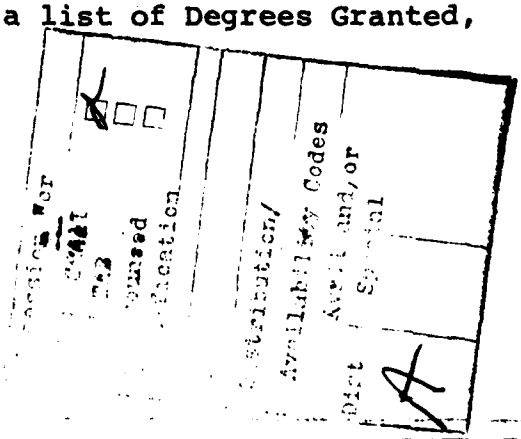
5. Study of Vibrational And Rotational Relaxations in $D_2O$

6. Doppler-Free Spectroscopy With a Two-Beam $CO_2$ Laser Spectrometer

7. XeF Ground-State Dissociation And Vibrational Equilbration[a)]

The report is concluded by a list of Degrees Granted, and a list of publications.





## 1- High-Speed Submicron Junctions; Optical Electronics

The original work of thie laboratory in the area of extension of microwave detection and frequency measuring technologies, has taken place in several stages and over a number of years. The early work was performed with the high-spped elements consisting of a mechanically contacted high-speed metal-barrier-metal junctions. This work was followed by utilization, for the first time, of thin-film evaporated high-speed junctions, integrated with thin-film IR autennea structures. The latter has a varierty of possibilities for FIR and IR phased-array structures, and others.

In the period covered by this report, the emphasis was shifted to a study of the high-speed elements under highly controlled conditions. The objectives were two-fold: The first consisted of obtaining experimental features of a junction which would remain "high-speed" over a broad frequency interval, extending from the rf, upto the near IR and visible range. The second objective was to understand the physical processes occuring in the junctions.

In the area of high-speed metal-to-metal submicron junctions, the I-V characteristics of the junctions at rf and microwave frequencies were extensively studied under highly controlled conditions. The results were compared with the observed IR or visible responses of the junctions and their high-speed frequency mixing properties.

The studies have reproducibly shown the presence of rapid variations of the I-V curves occuring over narrow ranges of bias voltages. These give rise to resonances centered at fixed bias fields, superimposed on the second derivative of the I-V curves. The second derivative curves (proportional to junction's responsivity) are obtained over a broad frequency interval, with features which are identically maintained from the rf upto the near-IR. The resonances considerably enhance the IR responsivity of the junctions at fixed bias fields.

The observations are made at cryogenic tempertures in the mechanically contacted high-speed junctions. It is shown that under the appropriate conditions, highly stable junctions of this type can be obtained. The local stresses in the junctions are measured and shown to be in the kilobar range. The junction contacts under varying stresses are studied with stero electron micigraphy, to determine their submicron demensions and the related details in their contact areas.

The reproducible resonances noted are observed in the zero-bias region, as well as at finite bias voltages in the W-Ni junctions. The finite bias resonances appear at bias voltages corresponding to the W-Fermi level below the Ni Fermi level.

The resonance centered at the zero-bias is associated to a zero-bias amonialy and is studied at magnetic fields up to 100,000 Gauss. For the finite bias resonances, strong evidence is obtained that they orginate from a surface effect associated to Ni-Ferromagnetism. The zero-bias resonances on the other hand, are believed to originate from an electron relaxation process.

The bias voltages at which the finite bias resonances occure are found to be both stress and magnetic field dependent. Such dependences (highly reproducible) are quantitatively studied. The widths of the observed resonance are narrow and on the order of about five kT (expressed in electron volts).

A broader set of resonances are also observed. They are centered exactly at locations of longitudual phonon modes of Ni, obtained from neutron diffraction studies. The observed resonances are investigated at rf, microwaves and IR frequencies.

Both Ni-single cystal as well as polycystal Ni have been studied under varying local stresses. Furthermore, junctions consisting of other metals, have also been studied in detal. These include metal-superconducting junctions, as well as superconductor-superconductor junctions. Band gap effects and their magnetic field dependences are observed.

Thin film evaporated normal metal-superconductor junctions, and superconductor-superconductor junctions have also been studied at the rf, IR and the visible frequencies. Responsivities of the junctions at these frequencies versus varying bias voltage are studied in detail. The signals (proportional to second dirivatives of the I-V curve), dramatically follow identical curves, with respect to the resonant features caused by the superconductor band gap Slight deviations on the background response, at the He-Ne 6328Å and several Ar-ion laser frequencies are observed and tentatively explained.

The resonant features observed are superimposed on a broad background variation of junctions' response versus bias voltage. This background variation is observed in the mechanically contacted junctions under controllably

varying stresses. The observations are made in the rf and IR frequencies.

For the junctions with measured contact areas having dimensions in the several thousands Angstrom range and local stresses causing juction resistances in the range of 100 ohms or higher, the broad background response-versus-bias, quantitatively follow predictions of an electron tunneling process accross thin barriers, with barrier-heights in the range of several tens of volts. The barrier-heights are determined by curve fittings of the background response versus bias voltages, with the prediction of an electron tunning process. The observed heights are found to be reproducibly dependent on the measured magnitude of the local stress in the junctions.

In addition, higher-order requency-mixing effects in which two or three different applied frequencies are mixed in a junction, are studied versus applied bias voltages. The quantitatively measured results also follow predictions of high-order nonlinearitiers of electron tunneling process, with the high-speed properties caused by Fermi-level modulation due to the applied rf or optical fields. The measured barrier hights, determined from the observation of frequency mixing signals at different orders or the responsivity curve, conssistantly predict the same barrier-height in a given junction at a fixed measured local stress. Because of very thin barriers (observable only in the submicron junctions), a WKB approximation for the estimate of the tunnelling process is not appliable. The theoretical analysis are done by computer calculations.

For the submicron-junctions at local stress values corresponding to resistances of about tensof Ohms or lower, an appreciably deviation is observed from prediction of the electron tunnelling process. Precisely in such junctions, however, the current densities are extremly high, and in a range where current saturation can become appreciable. A

full understanding of such processes required further experimentation.

The experiments are difficult to perform. However, once the observations are made under carefully controlled conditions as reported above, reproduciabl results as outlined can be obtained.

A summary of portions of this work has been published in a Physical Review Letters.[1] . An extensive review paper is being prepared for publication of considerabl additional details, as summarized above.

## 2- Accurate Laser Wavelenghts Measurements With A Precision Two-Beam Interferometer

An extensive work, underway over a number of years at this laboratory, has been concluded and reported in a major publication[2] in the Journal of Applied Optics. The artical gives the details of a precision two-beam scanning Michaelson interferometer, designed and perfected for accurate comparision of an unknown laser wavelenght and the precisely calibrated wagelength of a reference laser. An iodine Lamp-dip stablizer He-Ne 633nm laser (calibrated with respect to a Kr Standard) is used as the reference. The design incorporated features to minimize instrumental errors and the effects of fringe shifts caused by diffraction (in the IR). It is applied to accurate measurements of a stable $CO_2$ laser wavelength tuned to the centers of its various transitions. Measurements are done by simultaneous fringe counting and relative fringe-phase comparison at the two wavelenghts employing on-line data storage and processing with an electronic digital computer. The accurancy in the 10$\mu$m region is several parts in $10^9$, and is limied by correction for diffraction fringe shifts. Because of its

low-Q and broad-band operating characteristics, it can be applied to rapid accurate laser wavelenght measurements over the entire wavelength range permittied by its transmitting optics. In the visible range where the diffraction correctinn is small, the interferometer can be used to perform measurements to within several parts of $10^{11}$. The paper gives theoretical derivation of various diffraction corrections, the design and construction of the interforometer, the alignment procedures, detailed analysis of various error sources, and data processing. It also gives the details of the previously reported accurate measurement of the speed of light employing the measured wavelenght of the $CO_2$ R (14) line and its know frequency. Other interforometric laser wavelenght mea.urements are brie:ly reviewed.

3- Laser Spectroscopy With A Tunable High Pressure $CO_2$ Laser

The use of a continously-tunable (10 atmospheres) high pressure $CO_2$ TEA laser, to optically pump a methyl alcohol far infrared (FIR) laser, at frequencies appreciably detuned from $CO_2$ line centers is extensively explored in this period. The capability to pump vibrational-rotational transitions in $CH_3OH$ which lie between $CO_2$ line enters is exploited to substantially increase the number of purely rotational FIR lasing transitions obtainable and to permit systematic spectroscopic investigation of the first exciting CO-stretch ($V_5$=1) vibrational state of methanol. This is the first reported[3] application of a tunable TEA laser to spectroscopy.

The TEA laser developed for this purpose is UV-photo-preionized double-discharge type employing trimethylamine, $(CH_3)_3N$, as a seed gas to aid preionazation. $(CH_3)_3N$ is found to be chemically stable in a glow-discharge --solving

the polymerization problem of many other organic seed gases and permitting practical operation of this covenient and effecient type of laser to 10-15 atmospheres for the first time. Using a grating-tuning cavity, linear turning is achieved accross four continuous 15cm$^{-1}$ wide bands of overlapped pressure-broadended lines. The laser generates 50 nsec pluses of 200-400 kW peak power with a band width of 2 CHz FWHM.

Use of this laser to pump $V_5 = \rightarrow 1$ transitions in $CH_3OH$ leads to many new FIR laser emission lines. Accurate measurements of pump and lasing frequencies of 55 entirely new lines in the far-IR range are reported. Many of these lines and several others previously preported are identified with specific pumping and laser transitions. These assigngments are made using general expressions developed for pump and lasing frequencies and the small-signal gain of the optically pumped FIR laser. The expressions and generalizations developed from them, predict where FIR lines may be found. However, a number of predicted lines do not last due to competition effects and self-absorption by the lasing media. This complicates the assignment process, but the tunability of the pump laser is found to be of great value since groups of related lines can be pumped-- a freedom not afforded by discrete-frequncy pumps.

On the basis of the identified transitions, the hight of the hindering barriers in the $V_5$=1 state ($H_1'$) is determined to be 396.9) cm$^{-1}$-- an increase of 21.3 cm$^{-1}$ from the ground state value. The measurement of $H_1$ is consistant with previous (less precise) infrared and microwave obsorption measurements.

Using this value for $H_1$, a new value is determined for the CO-stretch vibrational energy; 1029.47.29cm$^{-1}$. Also determined for the first time, is rotional constant $A_1$ 4.2576+.003 cm$^{-1}$. The previously measured value of $(B_1+C_1)$, 0.7979cm$^{-1}$ is confirmed.

4- Mixed Isotope Multiatmospheric Laser

A sealed transversely excited muliatmosphere pulsed laser is developed in which the active medium is a combination of three isotopes; $^{12}C^{16}O_2$; $^{12}C^{16}O^{18}O$; $^{12}C^{18}O_2$. Lasing action is obtained in all 12 vibrational-rotational bands with continuous tuning observed between line centers at pressures 1/2 and 1/4 of those required with conventional $^{21}C^{16}O_2$ laser.

5- Study Of Vibrational And Rotational Relaxations in $D_2O$

Vibrational-relaxation and rotional-thermalization time constants of the $D_2O$ (010) state are studied in detail. A rotatinal level with an exceptionally long rotational-relaxation time constant is identified.[5]

An extensive theoretical investigation was made, to explore the possibilities of utilization of such a colliscionally long-lived rotational level in a FIR laser. In the investigation, excitation by low-energy electrons were considered. Although this method was fairly promising, experimental work was not done, due to shortage of funds.

## 6- Doppler-Free Spectroscopy With a Two-Beam $CO_2$ Laser Spectrometer

Copropagating-beam Doppler-free resonances, observed in fluorescence, are ulilized to study vibrational dependence of $N_2O$ quadrupole typefine structure for several transitions of the (100-001) band. A novel technique is applied to simplify the spectra by using a large itensity ration for the beams.[6,7,8].

Employing the same spectrometer, the diamagnetic shift in the infrared Zeeman spectra of $CO_2$ is measured by [9] ulilizing coprpagating-wave-crossing resonances observed in florescence. This technique permits determination of the magnetic parameters for individual vibrational states. The diamagnetic suseptibility anisotropy and molecule gj factor for the (001) state are obtained from the spectrum for the R (0) transition of the 10.6 um band. The molecular quadruople moment $Q_{zz}$ (001) is estimated.

In these experiments two highly stable $CO_2$ lasers are used. The laser have intricate designs, developed over a number of years at this labaratory. The details of the designs and performances of the laser are reported in a publication.

## 7- XeF Ground-State Dissociation And Vibrational Equilbration

The time evolution of the population of XeF ground-electronic state vibration levels is studies[10,11] using a laser-induced fluorescent technique. The results indicate that a

quasiequilibrum distribution is rapidly established with the vibrational manifold and that the dissociation rate of the molecular ground state as a whole is (1.4+0.3) x $10^4$ $sec^{-1}$ $Torr^{-1}$.

## DEGREES GRANTED

S. NAZEMI, Ph.D. 1982

Dissertation: "Studies Of The Fundamental And High-Lying Vibrational States of Hydrogen Deuteride Molecule"

S.F. FULGHUM, Jr., Ph.D. 1980

Dissertation: "XeF Ground State Dissociation And Vibrational Equilibration"

R.B. GIBSON, Ph.D. 1979

Dissertation: "Far Infrared Spectroscopy Of Methyl Alcohol Using Continuously-Tunable Tea Laser Optical Pumping"

K.C. LIU, Ph.D. 1979

Dissertation: "Characteristics Of Point Contact Submicron Junctions And Their Applications"

## PUBLICATION LIST (REFERENCED IN THE TEXT)

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1- "Electron Tunneling Spectroscopy of High Speed W-Ni Submicron Junctions", K.C. Liu, C. Davis, Jr., and A. Javan, Phys. Rev. Lett. 43, 785 (1979).

2- "Accurate Laser Wavelenght Measurement With A Precision Two-Beam Scanning Michelson Interferometer", J.-P. Monchalin, M.J. Kelly, J.F. Thomas, N.A. Kurnit, A. Szoke and A. Javan, Applied Optics 20, 736 (1981).

3- To Be Published

4- "Mixed Isotope Multi-Atmosphere $CO_2$ TEA Laser", R.B. Gibson K. Boyer and A. Javan, IEEE J. of Quan. Electronics QE-15 1224 (1979).

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